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WHEN LASER-IRRADIATED

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DAMAGE MECHANISM OF InSb DETECTORS (PV) WHEN LASER-IRRADIATED*

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ABSTRACT: The damage mechanisms of InSb detectors (PV) when laser-irradiated are investigated. It is pointed out that the laser damage degrades the p-n junction locally, which has effects similar to those of a parallel resistance on device performance. Various experimental phenomena are explained. The calculated values closely fit the experimental data. This model can also explain the "flash" effects, i.e., the InSb (PV) detector may have better performance after irradiation with intense light.

Key Words: InSb detector, laser damage, "flash" effect.

When irradiated with a laser, a photoelectric detector is subjected to a temperature rise owing to absorption of laser energy and may even suffer damage under critical conditions. Many related papers [1-5] have been published on problems such as thermal models, damage threshold values, transient behavior, and the like. In the present experiment, it has come to our attention that laser damage to InSb (PV) detectors covers the following areas: a drop in open-circuit voltage, the V-I characteristic curve becoming straight, and the saturation open-circuit voltage remaining almost unchanged before and after the damage by laser irradiation (even when the voltage has dropped by a factor of several tens compared to the voltage prior to damage, at room temperature). Reference [6] outlines the performance

degradation of InSb detectors after many years' service as well as its restoration by the "flash" effect, but gives no further explanation. We have encountered similar problems [7], which are likely to have the same mechanism as laser damage. This paper proposes, based on very extensive experimentation, a parallel-resistance model of laser damage, which exhibits a perfect matched between theoretical concept and experimental result.

Experimental Phenomena and Their Explanations

1. Experimental Phenomena. Normally, laser damage does not necessarily imply that the InSb (PV) detector in question has completely lost its efficiency. Rather, once damaged, it can still respond to light, though its sensitivity has decreased, the noise has increased, the open-circuit voltage has been reduced, and the V-I characteristic curve has become straight. Fig. 1 shows the V-I curve before and after damage (a - before damage, b - after damage), where the point of intersection between curve and X-axis is the open-circuit voltage, which has apparently decreased after damage compared to before damage. Fig. 2 shows a transient-behavior curve [3] before and after damaged due to laser irradiation, where the open-circuit voltage corresponds to the saturation open-circuit voltage when a laser begins to irradiate. It is clear, according to Fig. 2, that the open-circuit voltage varies widely before and after damage at room temperature, when the saturation open-circuit voltage [4] remains nearly the same under laser irradiation.

2. Model. The p-n junction of the photoelectric detector (PV) is so close to the photosensitive surface (approximately 1μm) that it is proper to assume that the p-n junction melts locally by heat and changes over to a resistance under laser irradiation at a certain power (energy). In the case of local irradiation by a laser (as for light focused with a lens) or when laser flares appear uneven during large-area irradiation, usually only part of

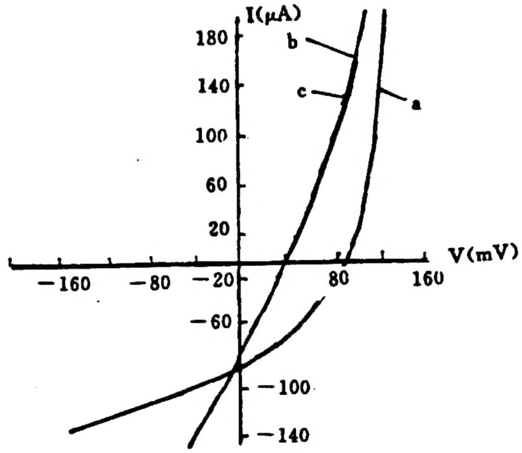

Fig. 1. V-I curve (a - value calculated before damage b - value calculated after damage c - calculations with a and Eq. (2): R=0.79K, E=9mV)

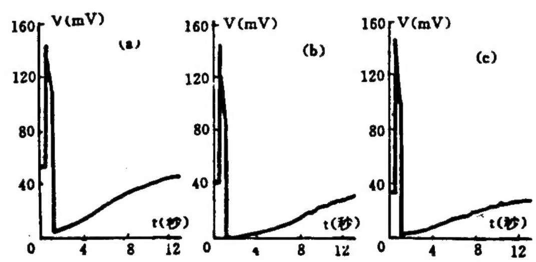

Fig. 2. Transient-behavior curve after laser irradiation
a - before damage b - after damage
c - simulation device

the p-n junction is degraded to form a resistance, while its unmelted portion still retains ideal p-n performance. Thus, a laser-damaged detector can be projected as an undamaged device with a parallel resistance, the extent of which depends on the extent of damage, i.e., the more severe the damage, the larger

the melted area and the lower the parallel resistance.

Fig. 3 shows the formulated model, where the undamaged device is equivalent to a series connection between E_D, the electromotive force, and R_D, the resistance; E_D is the photovoltaically generated electromotive force, and R_D is similar to a diode, whose size is associated with the electric current passing through and which can be derived from the V-I characteristic curve. In addition, R is the parallel-resistance equivalent in the after-damage model, while $R=\infty$, the value before damage. Obviously, all the V-I curves mentioned in this paper are defined as the V~I curve shown in Fig. 3.

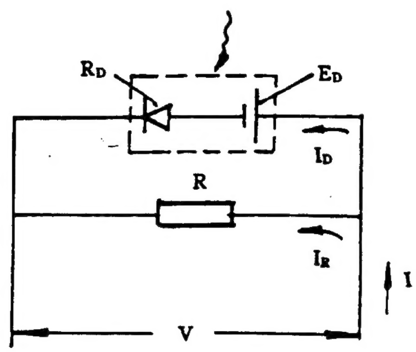

Fig. 3. Model

The plausibility of this model is described as follows:
(1) It is found that when focused laser light damages a PV detector in part, damage from multiple emissions of the pulsed laser at a single point appears much like that from a single emission at a single point. This is so because when a single pulsed laser has damaged a given part of the detector, the p-n junction at that site has already been degraded and therefore any repeated damage may not generate a new effect. To increase the effectiveness of damage, it becomes necessary to expand the damage area by using either large-area irradiation or multiple-

point irradiation with a repetition-rate pulsed laser.

(2) When an undamaged device mounted with a parallel resistance is applied to simulate a damaged device, its open-circuit voltage decreases under the background light at room temperature just as is the case in a damaged device, but under laser irradiation, its saturation open-circuit voltage remains basically identical to that in an undamaged device under laser irradiation as seen in Fig. 2(c). The reason is that under the background light at room temperature, the device has a higher internal resistance R_D (given by the V-I curve in Fig. 1(a)) and the presence of R produces a stronger effect on open-circuit voltage. However, under intense laser irradiation, E_D changes to a saturation photovoltaically generated electromotive force E_{DS} and a large number of photovoltaically generated carriers are formed inside the detector. As a result, the internal resistance R becomes very low and the open-circuit voltage V is equal to E ($V=E_{DS}$). Thus, the saturation open-circuit voltage in either the damaged device or the simulation device [4] is equal to that in the undamaged device.

The simulation device has a V-I curve similar to that in an undamaged device, i.e., it appears rather straight. Moreover, the lower the parallel resistance, the straighter the curve. We use the V-I curve of the undamaged device mounted with a parallel resistance to be fitted to the V-I curve of the undamaged device and acquire the value of the resistance. The V-I curve with a parallel resistance R can be expressed as follows:

$$I(V) = I_D(V) + I_R = I_D(V) + V/R \qquad (1)$$

where $I_D(V)$ is the undamaged-device V-I curve. Fig. 4 demonstrates that the value calculated from Eq. (1)b closely fits the experimental value.

(4) Both the experiment with the simulation device and Eq. (1) suggest that when V=0, $I(V=0)=I_D(V=0)$ appears, no matter how high

R is. Nevertheless, it is often found in the laboratory that the I(V=0) value of the damaged device moves upward, i.e., in the direction of the model axis, because damage to the p-n junction may lead to a smaller photosensitive surface and furthermore, to a reduction in the photovoltaically generated electromotive force at room temperature. In that case, Eq. (1) should be rewritten as follows:

$$I(V) = I_D(V + \Delta E) + V/R \tag{2}$$

where ΔE is the reduction in E_D, the photovoltaically generated electromotive force caused by the reduced photosensitive surface. Fig. 1 compares the calculations based on Eq. (2) and the experiment.

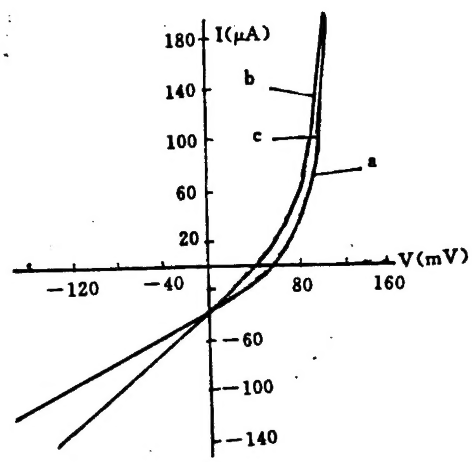

Fig. 4. V-I curve (a - value calculated before damage b - value calculated after damage and c - calculated based on (1), R=3.5KΩ)

(5) Flash effect. The flash effect, as outlined in [6], appears unrelated to the foregoing discussion, but it is probably an inverse process. After long service, the detector's photosensitive surface may absorb impurities; in addition, a host of microchannels may form between the p region and the n region, resembling numerous parallel resistances of high value. Yet on the whole, their resistance equivalent is not high, but high enough to affect detector performance. Under the action of the

flash effect as described in [6], surface impurities may be partly eliminated by optical absorption, which results in the improvement of device performance. The flash effect as mentioned in [6] normally can last up to a few minutes while irradiation with a CW YAG 1.06μm laser takes only a few seconds [7] as the laser heat can accelerate optical absorption. This kind of flash effect requires a selection of certain wavelengths, that is, light with a wavelength smaller than 1.3μm, which indicates a photochemical effect, not simply a thermal effect.

(6) Contrary to (4), there are exceptional cases arising from the experiment in which the I(V=0) value on the V-I curve of the damaged device moves downward when E_D increases rather than decreasing. In this event, if E<0 is selected in Eq. (2), it can still fit closely the experiment as indicated in Fig. 5, which, by an ideal interpretation, occurs accompanied by the flash effect. And as the damage is increased, I(V=0) will eventually increase.

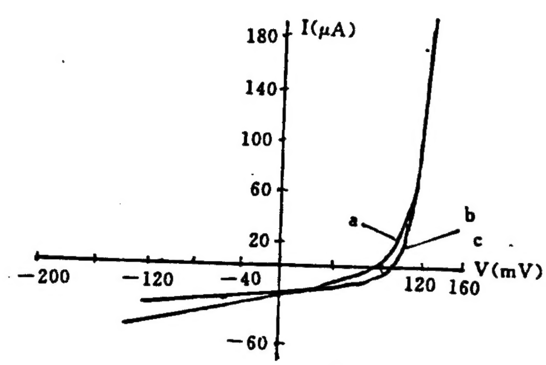

Fig. 5. V-I curve (a - value calculated before damage b - value calculated after damage and c - calculated based on (1), R=9.0KΩ, ΔE=-7mV)

Conclusions

By using the laser-damage model of the PV detector proposed in this paper, various phenomena related to detector laser damage are satisfactorily explained both as to theory and experimentation and thus it is emphasized that the extent of damage primarily depends on the area affected.

It is noted that when the detector has been damaged, no distinct traces of the damage can be seen even under a more than 100-power microscope. Evidently, its damage threshold value is apparently lower than that of the material (the defined threshold value of the material usually includes a burn track or melting), for which the microscopic mechanism of detector damage must be investigated.

Technically, the flash effect should be of significance in both theory and practice, which is given a qualitative explanation in this paper. However, further study should be focused on the surface structure of the device.

The validity of this experiment as applied to other devices is yet to be verified.

* This is a sponsored project in the field of laser technology under the State High-Tech Program. The paper was received for publication on September 1, 1994.

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